MAGNETORESISTIVE SENSOR WITH MAGNETOSTATIC COUPLING OF MAGNETIC REGIONS

FIELD OF THE INVENTION

[0001] This invention relates to magnetoresistive sensors and more particularly to giant magnetoresistive effect (GMR) sensors using controlled magnetostatic coupling to obtain opposite alignment of magnetic regions of soft magnetic materials.

BACKGROUND OF THE INVENTION

[0002] The giant magnetoresistive effect (GMR) depends on having magnetic regions which are not aligned with respect to each other in a zero amplitude magnetic field. When the magnetic regions are at saturation in a magnetic field, the magnetization in the magnetic regions are fully aligned. The GMR of magnetic regions in magnetic saturation is defined as the change in resistance from zero magnetic field to the resistance at magnetic saturation normalized by the zero field resistance.

[0003] Giant magnetoresistance has been discovered in magnetic multilayers. In a publication by S. S. P. Parkin et al., Phys. Rev. Lett. 64, 2304 (1990), the magnetoresistance in metallic superlattice structures of Co/Ru, Co/Cr, and Fe/Cr was reported. Values of $\Delta R/R$ of up to 33 percent have been observed in a Fe/Cr superlattice structure. This can be compared to $\Delta R/R$ of a few percent for the anisotropic magnetoresistance of a simple permalloy thin film sensor.

[0004] In a publication by W. P. Pratt et al., Phys. Rev. Lett. 66, 3060 (1991), in magnetic multilayers of Ag/Co, the magnetoresistance with the current flow perpendicular to the layer has the largest change of resistance, for example, near 50 percent as compared to the magnetoresistance of current in the plane of the layer which may have a $\Delta R/R$ of 12 percent. Also, in multilayer structures, the magnetic fields required to obtain the large values of $\Delta R/R$ are very large because the magnetic field must be sufficient to overcome the antiferromagnetic exchange between the layers. These magnetic fields are much larger than the fringing field of a magnetic transition on a disk or tape representing stored data.

[0005] In exchange coupled films, the magnetic field required to align the oppositely magnetized regions depends on the strength of the antiferromagnetic exchange between the layers. The magnetic field required to align the oppositely magnetized regions tend to be very large, for example, on the order of 10 kOe.

[0006] A spin valve is a sandwich structure of two magnetic layers with a nonmagnetic layer between such as described in U.S. Pat. No. 5,159,513 which issued on Oct. 27, 1992 to B. Dieny et al. In a spin valve, one magnetic layer has its magnetic orientation fixed, usually by exchanged coupling. The other magnetic layer is free to switch in the applied field except for its own coercivity (Hc) hysteresis. The resistance of the device is highest when the magnetic fields are oppositely aligned or aligned perpendicularly and the lowest resistance is when the magnetic fields are aligned. The magnitude of the giant magnetoresistive effect in spin valve structures may be seven to nine percent as shown in U.S. Pat. No. 5,159,513 which is not as high as in multilayer structures.

[0007] The giant magnetoresistive effect has also been reported in granular thin films in a publication by J. Q. Xiao et al., Phys. Rev. Lett. 68, 3749 (1992). These granular thin films consist of small phase separated single domain magnetic particles, for example, Co in Cu, a nonmagnetic conductive matrix. So far, the giant magnetoresistive effect has only been observed in a limited set of materials which phase separate into suitable magnetic and nonmagnetic regions. The magnetization is oriented along the easy axis of each particle which varies randomly from particle to particle. The magnetic field must overcome the magnetocrystalline anisotropy and the shape anisotropy of the Co particles. In addition, if there is any interfacial strain at the Cu/Co interface, there may be an additional anisotropy through the magnetostriction (λ). The magnetic field necessary to overcome the random directions by local anisotropy is on the order of 10 kOe. Also, $\Delta R/R$ is smaller than in multilayer structures, probably because the change in alignment is less extreme, being from random to parallel rather than from perpendicular to parallel or antiparallel to parallel.

SUMMARY OF THE INVENTION

[0008] In accordance with the present invention, an apparatus for sensing a magnetic field by the giant magnetoresistive effect (GMR) is described comprising a plurality of magnetic stripes spaced apart on the upper surface of a substrate such that the stray fields at the ends of the magnetic stripes provide a magnetostatic coupling which magnetizes the magnetic stripes in alternating directions in a zero magnetic field, a nonmagnetic conductive material such as copper, positioned in the spaces between the magnetic stripes to form a conductive path between respective stripes, and terminals or electrodes for introducing a current along the conductive path for detecting the change in resistance through the plurality of stripes and conductive paths as a function of magnetic fields applied to the magnetic stripes. The magnetic stripes may be rectangular in shape and spaced apart from one another by at least a 100 Å to prevent any exchange coupling. The magnetic stripes may comprise a soft magnetic material. The electrostatic coupling between ends of magnetic stripes may be enhanced by positioning transverse magnetic stripes over or abutted to the ends which function as permeable "keepers". The cross-sectional areas of the magnetic stripes may be less than 1000 Å square. The apparatus is suitable for incorporation in a head for sensing a magnetic disk in a magnetic disk operating system. When the magnetic stripes are magnetized in alternating directions, a high resistance state is measured to current passing through the plurality of magnetic stripes and when a magnetic field causes the magnetic stripes adjacent one another to be magnetized in the same direction, a low resistance state is measured to current passing through the plurality of magnetic stripes.

[0009] The invention further provides, a method for fabricating a magnetic head comprising the steps of orienting, cutting and polishing or selecting a single crystal substrate having a surface at an angle between 1 and 100 away from a major crystallographic plane, annealing the crystal to produce atomic scale steps on its surface, depositing a ferromagnetic metal such as Fe, Co, or Ni or alloys thereof onto the single crystal substrate surface, overcoating the ferromagnetic metal with a nonmagnetic metal of comparable thickness and planarizing the nonmagnetic metal to